Research on the obstacle dynamics of a legged-wheel composite mine rescue robot

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Abstract

Aiming at the movement requirements of rescue robots in complex mine environment, a new type of leg-wheel hybrid robot Mine-Titan was designed and a dynamic model of obstacle-obstacle was established. Firstly, based on the common step obstacles in mines, a compound moving mechanism with front and rear leg telescopic functions was designed. Based on this, the robot obstacle height formula was established. Secondly, the dynamics of the entire obstacle process of the robot is discussed. Finally, the rationality of the robot structure and dynamics model is verified by simulation.

Keywords

Six-wheel-leg hybrid mobile robot; obstacle negotiation; structural design; dynamic formulation.

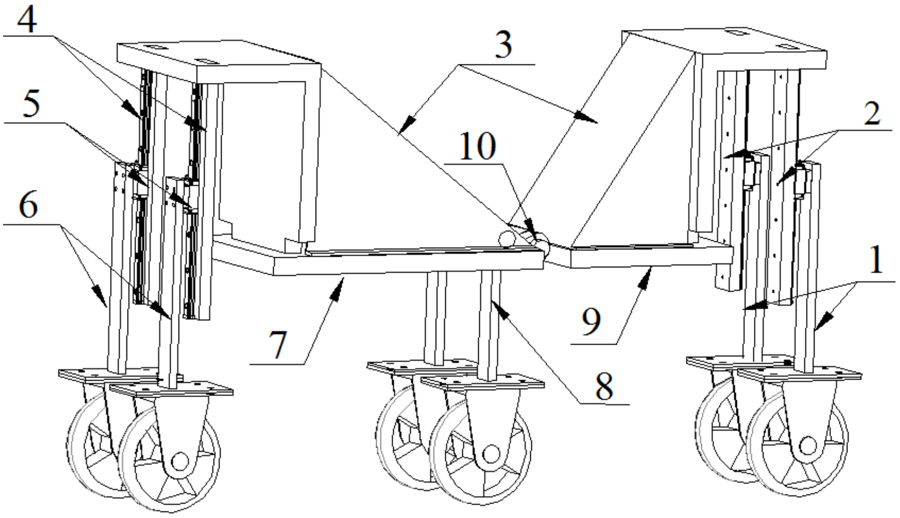
1. Introduction

A mobile robot is a type of robotic system that can realize a certain operational function by sensing the environment and its own state through sensors, and achieving autonomous movement in the obstacle environment. The use of mobile robots for search and rescue (SAR) survivors in dangerous, harsh and complex disaster environments is an important application area for mobile robotics.Coal mine disasters in China are frequent and extremely harmful. In many cases, ambulance personnel cannot enter dangerous areas, and the participation of rescue robots can effectively improve rescue efficiency and reduce casualties. They can not only help ambulance personnel to carry out rescue work, but also can replace ambulance personnel to perform search and rescue missions, playing an increasingly important role in disaster relief. At present, extensive and indepth research on rescue robots has been carried out at home and abroad. It has become a research hotspot to find mobile robots suitable for coal mine working environment.

In this paper, a new type of leg-wheel compound mine rescue robot is designed and named as Mine-Titan for the movement requirements of rescue robots in complex mine environments. The Mine-Titan robot has retractable front and rear legs that can span most of the Common obstacles in mine roadways have good adaptability to mine topography.

2. Robot structure design

The structural design is a fusion of the quadrilateral mechanism and the telescopic leg structure, so that the wheel-leg composite robot has a waist rotation and a leg telescopic function, mainly by the front wheel leg, the front car body, the rear car body, and the rear wheel. The legs, the middle wheel legs, etc., as shown in Figure 1.



1. Front wheel movable leg 2. Front wheel fixed leg 3. Protective cover
4. Rear wheel fixed leg 5. Slider guide6. Rear wheel movable leg 7. Rear body
8. Intermediate wheel leg 9. Front body 10. Car body rotating drive shaft

Figure 1 Wheel-leg composite robot structure

The structural characteristics of the Mine-Titan leg wheel composite robot are as follows:

(1) The front and rear body is designed as a Z-shaped structure, which greatly helps the overall obstacle-obstacle ability of the robot;

(2) Adopting a six-wheel mobile system, which has strong adaptability and obstacle-obstacle ability, the steering of the robot is realized by the slipping manner of the wheel;

(3) The corresponding wheel legs in the step-type obstacle crossing process are not in contact with the obstacles, reducing the impact of the obstacles on the robot during the obstacle crossing process, and improving the obstacle stability of the robot;

3. Dynamics modeling and obstacle analysis

The static analysis of the robot is only suitable for the analysis under steady state, and is not suitable for the analysis of the dynamic process. Only the analysis of the dynamic process can determine the structural requirements of the robot and the motor power. In order to establish a more precise control model and simulation of the robot, the dynamic model of the robot is also needed. Only through the dynamic model can the robot's working condition be simulated more realistically.

Because the obstacle-blocking process of the stepped obstacle in the mine rescue environment is the most complicated, it is used as the research object to carry out the specific obstacle dynamics analysis. For research convenience, based on crossing vertical barriers (step barriers), make the following assumptions:

(1) The ground is rigid;

(2) Do not consider the friction between parts during the movement of the Mine-Titan robot;

(3) The wheels on both sides of the Mine-Titan robot remain in the same state during the movement;

(4) Ignore the deformation caused by the interaction between the wheel and the ground.

3.1 Front wheel obstacle

As the distance between the Mine-Titan robot and the obstacle is close, the initial condition of the obstacle is generated. When the ground support and the ground friction of the current wheel are reduced to zero, the front wheel begins to overcome obstacles in the front wheel of the robot. When in the jump phase, the center of gravity of the robot is continuously moved back, so that the support force of the ground for the rear wheel and the intermediate wheel increases with the increase of the pitch angle of the car body, and the attitude of the front wheel of the Mine-Titan robot is Figure 2 shows:

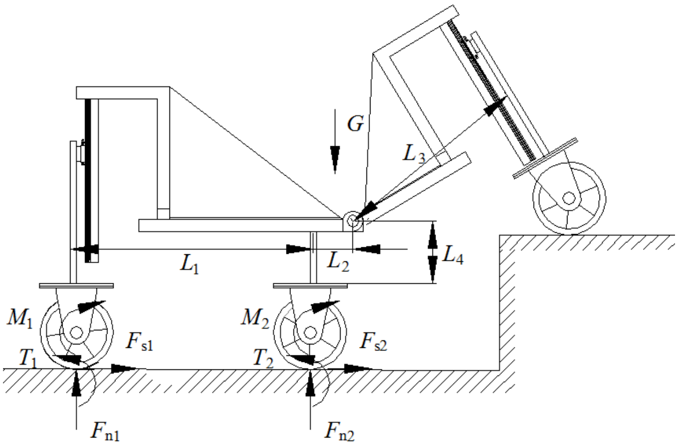


Figure 2 Front wheel leg obstacle

At this time, the front wheel is not subjected to force, and the force analysis of the robot is performed:

$$\left\{\begin{aligned} &\sum F = F_{n1} + F_{n2} - \frac{G}{2} = 0 \\ &\sum M_O = T_1 + T_2 - (M_1 + M_2) - F_{n1}(L_1 + L_2) - F_{n2} \cdot L_2 + F_{s1}(L_4 + 2r) \\ &\quad + F_{s2}(L_4 + 2r) - m \cdot g \left[L_3 \cos \alpha_1 + \left(\frac{h}{2} + r \right) \right] - m_1 \cdot g \cdot L_3 \cos \alpha_1 \\ &\quad - m_2 \cdot g \cdot l_2 \cdot \cos \alpha_1 + m_3 \cdot g \cdot l_1 + (m_1 + m_2) \cdot g \cdot (L_1 + L_2) + m \cdot g \cdot L_2 \end{aligned}\right. \tag{1}$$

WhereT_i is the rolling resistance torque experienced by the drive wheel, M_i is the driving torque, L_i is the distance function, m is the wheel mass, m_1 is the active leg mass, and m_2 is the total mass of the front body, front fixed leg and front rail , m_3 is the total mass of the rear body, rear fixed legs, rear rails and middle legs.

3.2 Middle wheel obstacle crossing stage

The obstacle of the middle wheel of the robot is completed with the obstacle of the front wheel, the front wheel and the step start to contact, the robot continues to move forward, the center of gravity rises continuously, and the front and rear wheels of the robot appear to have a speed difference, and the middle wheel is no longer touched by the ground. At the time of force, the middle wheel began to move beyond the middle of the step until the middle wheel was completely in contact with the ground, and the middle wheel was completed. The obstacle posture of the obstacle robot in the middle of the obstacle is shown in Figure 3.

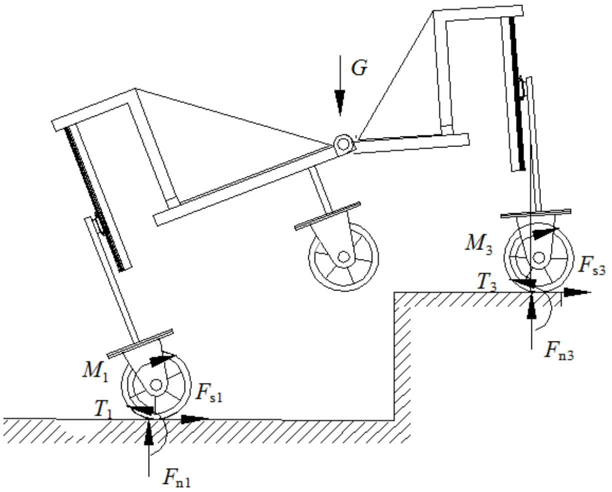


Figure 3 Middle wheel leg obstacle

At this time, the middle wheel is not stressed, and the force analysis of the robot:

$$
\begin{gathered}
\sum F = F_{n1} + F_{n3} - \frac{G}{2} = 0 \\
\sum M_O = T_1 + T_3 - (M_1 + M_3) - F_{n1}\left[(L_1 + L_2)\cos\alpha_2 - \left(\frac{h}{2} + 2r\right)\sin\alpha_2\right] + \\
F_{n3}\left[L_3\cos\alpha_3 + \left(\frac{h}{2} + 2r\right)\sin\alpha_3\right] + F_{s1}\left[(L_1 + L_2)\sin\alpha_2 + \left(\frac{h}{2} + 2r\right)\cos\alpha_2\right] \\
+F_{s3}\left[L_3\sin\alpha_3 + \left(\frac{h}{2} + 2r\right)\cos\alpha_3\right] - m\cdot g\left[L_3\cos\alpha_3 + \left(\frac{h}{2} + r\right)\sin\alpha_3\right] \\
-m_1\cdot g\cdot L_3\cos\alpha_3 - m_2\cdot g\cdot l_1\cdot\cos\alpha_3 + m_3\cdot g\cdot l_2\cos\alpha_2 + \\
m_1\cdot g\cdot(L_1 + L_2)\cos\alpha_2 + m\cdot g\cdot\left[(L_1 + L_2)\cos\alpha_2 - \left(\frac{h}{2} + 2r\right)\sin\alpha_2\right]
\end{gathered}
\tag{2}
$$

3.3 Rear wheel obstacle crossing stage

As the obstacle of the middle wheel is completed, the center of gravity is completely placed on the upper part of the step and moves forward. The front wheel starts to drive the whole drive, and the rear body lifts the rear wheel leg until the rear wheel completes the obstacle, the obstacle of the whole robot It is also completed.

When the rear wheel is over obstacle, as shown in Figure 4.

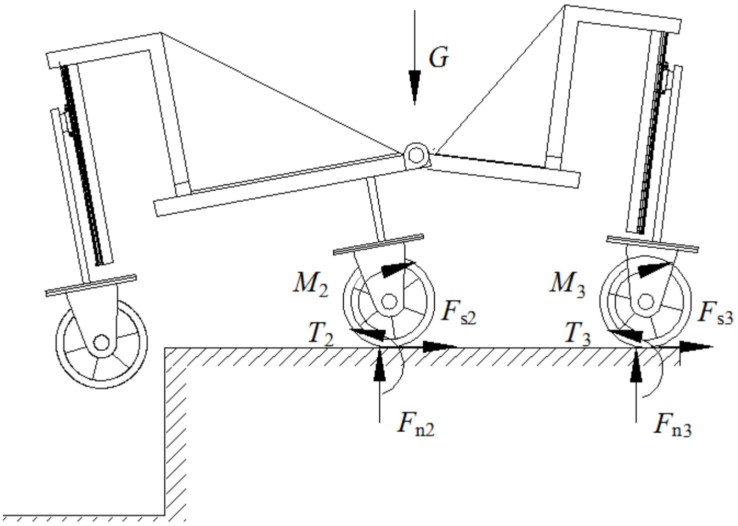


Figure 4 Rear wheel obstacle crossing stage

At this time, the rear wheel is not subjected to force, and the force analysis of the robot is performed:

$$
\begin{gathered}
\sum F = F_{n2} + F_{n3} - \frac{G}{2} = 0 \\
\sum M_O = T_2 + T_3 - (M_2 + M_3) - F_{n2}[L_2\cos\alpha_4 - (L_4 + 2r)\sin\alpha_4] + \\
F_{n3}\left[L_3\cos\alpha_5 - \left(\frac{h}{2} + 2r\right)\sin\alpha_5\right] + F_{s2}[L_2\sin\alpha_4 - (L_4 + 2r)\cos\alpha_4] \\
+F_{s3}\left[L_3\sin\alpha_5 + \left(\frac{h}{2} + 2r\right)\cos\alpha_5\right] - m\cdot g\left[L_3\cos\alpha_5 - \left(\frac{h}{2} + r\right)\sin\alpha_5\right] \\
-m_2\cdot g\cdot l_1\cdot\cos\alpha_5 + m_3\cdot g\cdot l_2\cos\alpha_4 - m_1\cdot g\cdot L_3\cos\alpha_5 \\
+m\cdot g\cdot\left[L_3\cos\alpha_5 - \left(\frac{h}{2} + r\right)\sin\alpha_5\right] + m_1\cdot g\cdot(L_1 + L_2)\cos\alpha_4 \\
+m\cdot g\cdot\left[(L_1 + L_2)\cos\alpha_4 - \left(\frac{h}{2} + 2r\right)\sin\alpha_4\right] + m_1\cdot g\cdot L_3\cos\alpha_5
\end{gathered}
\tag{3}
$$

4. Simulation

The 3D model of the robot is built by Solidworks, the file is saved in parasolid (*x_t) format, and then imported into the ADAMS virtual prototype to establish the corresponding constraints and then simulate. The robot's entire obstacle-obscuring process time is set to 12s. Through the simulation and post-processing, the simulation animation of the corresponding step obstacle is obtained. The simulation of the obstacle process is shown in Figure 5. In order to simplify the observation of the simulation model and the simulation process, the front and rear protective covers are removed during the simulation, and the steering problem of the vehicle body is not considered, and only the linear motion is analyzed, so parallel constraints are added to the vehicle body and the ground simulation.

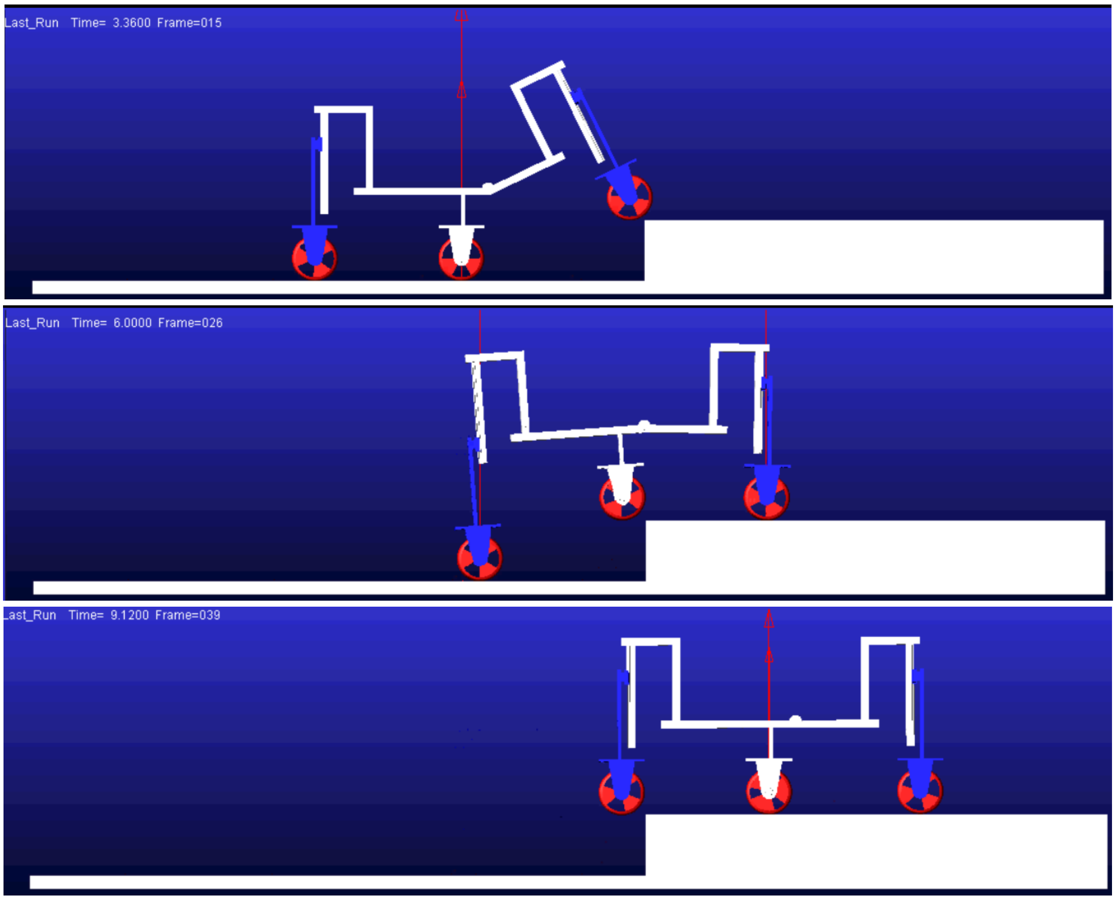


Figure 5 Stepped obstacle process simulation

5. Conclusion

In this paper, according to the obstacle-obstacle requirements of robots in unstructured complex environment, a cross-barrier robot with waist rotation and front and rear wheel leg extension functions is designed. The robot structure has the characteristics of increasing the barrier performance, reducing the obstacle to the wheel strike, increasing the obstacle stability, and establishing a comprehensive dynamic model for the entire obstacle process. Finally, by establishing a combination of 3D model and virtual prototype, the feasibility of the obstacle obstacle of the obstacle to the step obstacle is verified. Based on the previous work, the follow-up will be based on the real-time contact control of the wheel and the ground and the control of the entire obstacle-obscuring process.ground and the control of the entire obstacle-obscuring process.

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